

Note: This article will be published in a forthcoming issue of the *Journal of Sport Rehabilitation*. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofed, or formatted by the publisher.

Section: Original Research Report

Article Title: A Three Week Unexpected Disturbance Program Improves Physical Performance of Elite Female Athletes

Authors: Jorg Teichmann¹, Edin K. Suwarganda¹, C. Martyn Beaven¹, Kim Hébert-Losier¹, Lee Jin Wei¹, Florencio Tenllado Vallejo¹, Philip Lew Chun Foong¹, Ramlan Abdul Aziz¹, Yeo Wee Kian¹ and Dietmar Schmidtbleicher²

Affiliations: ¹National Sports Institute of Malaysia, Bukit Jalil, Malaysia. ²Johann Wolfgang Goethe University, Frankfurt am Main, Germany.

Journal: *Journal of Sport Rehabilitation*

Acceptance Date: November 17, 2016

©2016 Human Kinetics, Inc.

DOI: <http://dx.doi.org/10.1123/jsr.2016-0082>

Manuscript title: A Three Week Unexpected Disturbance Program Improves Physical
Performance of Elite Female Athletes

Brief running head: Unexpected Disturbance Training and Performance

Research conducted at the Malaysian National Sports Institute

Jorg Teichmann¹, Edin K. Suwarganda¹, C. Martyn Beaven¹, Kim Hébert-Losier¹
Lee Jin Wei¹, Florencio Tenllado Vallejo¹, Philip Lew Chun Foong¹, Ramlan Abdul Aziz¹,
Yeo Wee Kian¹ and Dietmar Schmidtbleicher²

¹National Sports Institute of Malaysia, Bukit Jalil, Malaysia.

²Johann Wolfgang Goethe University, Frankfurt am Main, Germany.

Address for correspondence:

Dietmar Schmidtbleicher, Ph.D.
²Johann Wolfgang Goethe University,
Frankfurt am Main,
Germany.

Phone: +49 69 798 24524

Fax: +49 69 798 24574

e-mail: Schmidtbleicher@sport.uni-frankfurt.de

ABSTRACT

Context: Sensorimotor training is commonly used in a rehabilitative setting; however, the effectiveness of an unexpected disturbance program (UDP) to enhance performance measures in uninjured elite athletes is unknown. **Objective:** To assess the impact of a three-week UDP program on strength, power, and proprioceptive measures. **Design:** Matched-group, pre- post design. **Setting:** National Sports Institute. **Participants:** Twenty-one international-level female field hockey athletes. **Interventions:** Two 45 min UDP sessions were incorporated into each week of a three week training program (total 6 sessions). **Main Outcome Measures:** One-repetition maximum strength, lower limb power, 20 m running speed, and proprioception tests were performed before and after the experimental period. **Results:** Substantial improvements in running sprint speed at 5- ($4.4 \pm 2.6\%$; Effect Size [ES]: 0.88), 10- ($2.1 \pm 1.9\%$; ES: 0.51), and 20-m ($1.0 \pm 1.6\%$; ES: 0.23) were observed in the UDP group. Squat jump performance was also clearly enhanced when compared to the control group ($3.1 \pm 6.1\%$; ES: 0.23). Small but clear improvements in maximal strength were observed in both groups. **Conclusion:** A three week UDP can elicit clear enhancements in running sprint speed and concentric-only jump performance. These improvements are suggestive of enhanced explosive strength and are particularly notable given the elite training status of the cohort and relatively short duration of the intervention. Thus, we would reiterate the statement by Gruber and colleagues (2004) that sensorimotor training is a “highly efficient” modality for improving explosive strength.

Key words: Strength, Sprint Speed, Power, Rate of Force Development, Field Hockey

Sensorimotor training has been incorporated into rehabilitation programs in athletic populations and can improve static postural sway and dynamic balance in both athlete and non-athlete populations¹. However, the rehabilitative exercises performed often represent relatively slow perturbations to human sensorimotor function (>350 ms) while empirical observations suggest that injuries occur in a time span of between 17 and 50 ms after initial ground contact². Moreover, most of these exercises occur in a controlled and predictable manner whereas, when competing, athletes are required to perform in an unpredictable environment, with a majority of anterior cruciate ligament injuries occurring during non-contact or indirect contact situations involving sudden unexpected dynamic perturbation^{2,3}. An ‘Unexpected Disturbance Program’ (UDP) has been demonstrated to be effective in promoting positive outcomes during the final phase of a rehabilitation program in high performance athletes⁴. In addition, an UDP has been shown to be more effective than traditional rehabilitation in returning athletes to high-level physical activities and promoting the maintenance of performance gains following rehabilitation of anterior cruciate ligament injuries⁵.

Specifically, measures of maximal leg strength and power were improved with a three week UDP in athletes that had been cleared to return to training following knee injury after having completed four phases of a rehabilitation program⁴, namely: mobility; stability; muscular strength; and sports-specific movement patterns. These results are in-line with previous studies showing sensorimotor training to be “highly efficient” in enhancing explosive muscle strength⁶. Kean and colleagues⁷ demonstrated that six weeks of wobble board training increased vertical jump height in recreationally trained women, while potentially increasing knee joint protection due to increased activation of the rectus femoris. Further, in elite athletes, six weeks of sensorimotor training has been shown to increase jump

performance without a concomitant increase in maximal voluntary isometric strength or rate of force development⁸.

Thus, the objective of this study was to examine the effects of incorporating an unexpected disturbance program into a traditional sports training program using a matched, parallel group design. Based on previous research, we hypothesized that an UDP would enhance physical performance measures in a cohort of uninjured elite female field hockey athletes.

METHODS

Participants

Participants were 21 female field hockey athletes (age: 23.1 ± 4.1 yr) who were currently participating in training with the Malaysian senior national squad and preparing for a major international event. This study was performed in accordance with the spirit of the Helsinki Declaration and an institutional ethics committee reviewed the protocol prior to commencement. All athletes were informed about all the risks and procedures involved in this study and they gave their written consent prior to their voluntary participation in this study.

Procedures

Experimental Design

Stratified randomization was used to create two groups (UDP intervention [n = 11] and control [n = 10]) using a specific measure of lower limb neuromuscular capacity termed ‘Jump Reserve’ (the ratio of 24 cm drop jump height to squat jump height) as a covariate. The UDP was integrated into the standard training program of the intervention group. Each athlete completed six sessions over a three week period. Physical performance tests

(described subsequently) were administered before the commencement and after the conclusion of the UDP.

Training Program

All athletes performed their standard weekly team training consisting of: four on-field hockey skills sessions; one strength session; three hockey-specific agility and conditioning sessions; and one general conditioning session. The total weekly training time for the athletes was approximately 21 h. In addition, two 45 min UDP sessions were performed on Wednesday and Friday (see details below). Note that the control group also completed two 45 min sessions with the same exercises as the intervention group, but without any unexpected disturbance.

Unexpected Disturbance Program

The UDP exercises prescribed in the current study consisted of three exercises whereby the athlete was required to react to an unexpected disturbance applied either manually or visually while executing specific exercises. The first exercise involved three sets of eight drop jumps from a 24 cm box. An investigator standing behind the athlete would randomly push them lightly between the scapulae to provide the unexpected disturbance stimulus. The second exercise was three sets of eight 20 cm hurdle jumps with a 15 m run up. An investigator would stand on the far side of the hurdle (~3 m) and give a hand gesture to indicate to the athlete which foot they were required to land on while the athlete was mid-flight clearing the hurdle. The third exercise consisted of two sets of five 20 m running sprints with five minutes rest between sets. An investigator stood at the halfway point of the sprint and would randomly stick out an arm or leg that the athlete was required to avoid. The aim of these exercises was to create stimulus that required rapid, reactionary movements with

a short latency period of <200 ms. As stated above, the non-UDP control group performed all of the above exercises, but were not perturbed by the investigators during the exercises.

Physical Performance Tests

Within one week prior to the commencement of and within one week after the completion of the UDP, the following physical performance tests were administered in the following order: countermovement jump; squat jump; 24 cm drop jump; standing broad jump; maximal landing impact force; a time-to-stability balance test; and leg strength (one-repetition maximum back squat). A minimum of 5 min rest were provided between each test. The following day a 20 m running sprint and 20 m repeated running sprint was assessed with at least 10 min rest between the tests.

Countermovement Jump Test

The test procedure started with a standard 20 min warm-up inclusive of dynamic stretching and 5 min cycling on a stationary bike. Subsequently, three maximal effort unloaded vertical countermovement jumps were performed on a contact mat (Swift Performance Equipment, Australia) with the hands on the hips and elbows turned outwards throughout the jump. The athlete lowered themselves into a self-selected half-squat position, and utilized the stretch-shortening cycle to jump with the instruction to achieve maximal height. The best jump height based on flight time was recorded and lower body instantaneous power was calculated. Each jump attempt was separated by one minute of passive recovery.

Squat Jump Test

The squat jump test replicated the countermovement jump test with the exception that the athlete was unable to utilize the stretch-shortening cycle as a 90° knee angle in the starting position was enforced. Prior to the explosive jump effort, the athlete was required to hold the squat position for 2 to 3 s. One minute of passive recovery was allowed between jumps.

Drop Jump Test

The athlete stepped off a 24-cm box on to the contact mat and were instructed to jump explosively immediately upon landing in an effort to achieve maximal height. The use of a 24 cm box has been suggested by Behm and Kibele⁹ stating that it would be high enough to stress the stretch-shortening cycle, whilst allowing participants to emphasize a short ground-contact time. As above, three jump efforts were performed separated by one minute of passive recovery and the greatest jump height was recorded.

Standing Broad Jump Test

The standing broad jump test was performed on a purposely designed rubber mat with 1-cm increments marked on to the non-slip surface. Using both feet, the athletes were instructed to jump forward as far as possible, with an arm-swing action permitted. The distance between the start line and the rearmost heel was recorded and the best of three trials was used for analysis.

Time-to-Stability and Landing Impact Force Tests

For the stability and landing force tests, a 20-cm hurdle was placed 2 cm in front of a force plate (400 Series Performance Force Plate, Fitness Technology, Australia) sampling at 200 Hz. From a two-leg standing position with hands on hips, the athlete was asked to jump over the hurdle and land on one leg on the force plate. The time-to-stability and ratio of impact force to body weight were automatically calculated by InnerBalance software (innervations, version 2013.01, Australia). Time-to-stability was defined as the difference between the landing time and the time at which stability within 5% of bodyweight was achieved.

Maximal Leg Strength Test

The one-repetition maximum (1-RM) back squat test was performed using a squat rack, Olympic bar and plates. After an initial warm-up with a 20 kg load, the athlete was instructed to do a light set of 8 to 10 repetitions with a load of approximately 100% of bodyweight (± 2.5 kg) which was measured prior to the test session on a previously calibrated weighing scale (Tanita, USA). The athletes then followed standardized procedures with incremental increases in weight until they were unable to lift the weight¹⁰. Each athlete was allowed a maximum of five sets to achieve their 1-RM. In those cases where 1-RM was not achieved after the fifth set, the Brzycki formula was used to predict the 1-RM using the set with the fewest repetitions¹¹.

20-m Running Sprint Test

The test procedure on the second day started with a standard 20 min warm-up inclusive of dynamic stretching and 5 min light jogging. The 20-m sprint test was assessed in a gymnastics hall using a dual-beam infrared timing system (Swift Performance Equipment, Australia) whereby four pairs of timing gates were set up at 0, 5, 10, and 20 m. The athletes performed three sub-maximal efforts at a perceived 50, 70, and 90% intensity before performing three maximal efforts. From a standing start position, the athletes were asked to sprint as fast as possible through the gates and to slow down only after they passed the final pair of timing gates. Each running sprint effort was separated by three minutes of passive recovery.

20-m Repeated Running Sprint Test

The same equipment from the 20-m running sprint test described above was used to assess repeated sprint performance. At least 10 min after the maximal running sprint test, each subject performed six 20-m running sprint efforts with 15 s of passive recovery between

each sprint effort. A work-to-rest ratio lower than 1:5 was implemented to minimize the contribution of the aerobic system through adenosine triphosphate resynthesis¹². Each sprint was timed and the cumulative sprint time was recorded.

Statistical Analysis

The dependent variables were log-transformed for the purpose of analysis and back transformation provided estimates of mean effects of the three-week intervention (i.e., pre versus post measures) as percentages and errors as coefficients of variations. Standardized changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-athlete standard deviations in the pre-test measures. Magnitudes of the standardized effects (Effect Size [ES]) were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate, and large, respectively¹³. Standardized effects of between -0.19 and 0.19 were termed trivial. To make inferences about the true (large-sample) value of an effect, the uncertainty in the effect was expressed using 90% confidence limits (mean \pm CL). The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects¹⁴. Thresholds for assigning the qualitative terms to chances of substantial effects were: <1 %, almost certainly not; <5 %, very unlikely; <25 % unlikely; 25–75 %, possibly; >75 % likely; >95 % very likely; and >99 % almost certain. The significance level was set at $p \leq 0.05$.

RESULTS

Maximal Leg Strength

Both the UDP (5.7 \pm 8.6%) and control group (7.9 \pm 6.0%) showed small but clear increases in back squat strength 1-RM, with no clear difference between the group responses.

Jump Tests (Figure 1)

Countermovement Jump Test (Figure 1A)

In the countermovement jump test, the UDP group showed a clear but borderline small/trivial increase in jump height ($2.2 \pm 2.3\%$; ES: 0.19). No difference in countermovement jump height was seen in the control group ($0.0 \pm 4.1\%$), resulting in a borderline small/trivial difference between the group responses ($2.2 \pm 4.5\%$; ES: 0.19).

In the squat jump test, the UDP group showed a clear but possibly trivial increase in jump height ($1.8 \pm 3.8\%$; ES: 0.14); whereas an unclear decrease was seen in the control group ($-1.3 \pm 5.0\%$). As a result, a small but clear difference was apparent between the group responses ($3.1 \pm 6.1\%$; ES: 0.23) in favour of the UDP group.

Drop Jump Test (Figure 1C)

There was no clear change in height achieved during the drop jump following the three-week intervention in either the UDP ($3.5 \pm 9.9\%$) or control group ($-0.1 \pm 9.7\%$). Consequently, there was no clear difference between the group responses.

Standing Broad Jump Test (Figure 1D)

In the standing broad jump test, the UDP group showed a clear but possibly trivial increase in jump distance ($0.9 \pm 1.8\%$; ES: 0.18). The control group did demonstrate a small and clear increase in jump distance ($1.5 \pm 1.7\%$; ES: 0.30), but there was no clear difference between the group responses.

20-m Sprint and Repeated Sprint Tests (Figure 2)

20-m Running Sprint Test (Figure 2A-C)

Substantial improvements in running speed were seen as a result of the UDP: 5 m ($6.1 \pm 1.0\%$; ES: 1.20); 10 m ($4.2 \pm 1.1\%$; ES: 1.02); and 20 m ($3.4 \pm 1.0\%$; ES: 0.78). Substantial improvements were also seen in the control group, but of a lesser magnitude: 5 m ($1.6 \pm 2.4\%$;

ES: 0.32); 10 m ($2.0 \pm 1.6\%$; ES: 0.51); and 20 m ($2.3 \pm 1.3\%$; ES: 0.54). Clear differences between the UDP and control group responses were apparent in the 5 m ($4.4 \pm 2.6\%$; ES: 0.88), 10 m ($2.1 \pm 1.9\%$; ES: 0.51), and 20 m ($1.0 \pm 1.6\%$; ES: 0.23) running sprint times in favour of the UDP group.

20-m Repeated Running Sprint Test

The cumulative time for the 20-m repeated running sprint test was clearly reduced following the UDP ($4.7 \pm 1.1\%$; ES: 1.15) and the control group ($3.8 \pm 1.1\%$; ES: 0.96). A clear but possibly trivial difference between the group responses was apparent ($0.7 \pm 1.5\%$; ES: 0.18).

Balance and Landing Force Tests

Time-to-Stability Test

The time taken for the athletes to achieve stability (within 5% of bodyweight) demonstrated a substantial improvement in both the UDP ($41.9 \pm 30.4\%$; ES: 1.00) and control group responses ($47.5 \pm 25.8\%$; ES: 1.19) with no clear difference between the group responses.

Landing Impact Force Tests

The impact forces experienced by the athletes upon landing after clearing the 20-cm hurdle decreased in both the UDP ($21.8 \pm 19.8\%$; ES: 0.69) and control groups ($33.0 \pm 16.2\%$; ES: 1.12). A small, clear difference between the groups was apparent between the group responses ($14.4 \pm 24.7\%$; ES: 0.43) in favour of the control group.

DISCUSSION

In confirmation of our hypothesis, a three week UDP led to substantially greater improvements in physical performance measures in elite female field hockey athletes when compared with an analogous training program without specific sensorimotor training. Specifically, the six sessions of the UDP were responsible for enhancements in 5-m, 10-m,

and 20-m running sprint speed and concentric-only jump performance. The improvement in running speed is of particular note, given our earlier findings that the beneficial effects of a six-week UDP in rehabilitating athletes on 20-m sprint speed appeared to be accentuated in males⁴.

Sensorimotor training has been demonstrated to elicit effects on neuromuscular function similar to resistance exercise training^{6, 15}. Specifically, increases in strength^{16,17} and the rate of force development (RFD) have been reported^{6,18,19}. Lauber and colleagues²⁰ also demonstrated that sensorimotor training elicited similar responses to resistance training; namely, an increased H-reflex following, reflective of enhanced motoneuron excitability, and improved integration of Ia afferent feedback²¹. It is noteworthy that strength gains were observed in both training groups in the current study, despite only three resistance training sessions being performed over the experimental period (i.e., one strength session per week). While there was no difference between the two experimental groups, the neuromuscular training associated with the experimental protocols could have potentially contributed to the substantial strength increases observed, which is consistent with lower-extremity strength gains reported in a cohort of female athletes following a neuromuscular training program²².

The enhanced RFD following sensorimotor training has been attributed to improved extrafacilitatory drive from the afferent system⁶. Changes in motoneuron recruitment, firing frequency, and synchronization have also been proposed to explain improved RFD^{6,21,23,24}. The importance of RFD in athletic performance is demonstrated by the observed relationships between RFD and both running speed and jump performance^{8,25,26}. Here we report substantial enhancement of running sprint speed and concentric-only jump performance in elite female athletes performing a UDP. The performance enhancement was particularly evident in the 5-m sprint running data (Figure 2A). As the initial acceleration phase is dominated by concentric muscle actions²⁷, here we suggest that the UDP-mediated improvements in both

running sprint time and the concentric-only jump performance are indicative of enhanced RFD.

The magnitude of the observed improvements in running speed and jump performance attributable to the UDP, although objectively small to moderate, are noteworthy given the elite training status of the cohort and the relatively short duration of the intervention (six sessions performed over a three week period). It is however known that, sensorimotor training on a stability platform can induce structural changes in brain regions known to be associated with complex motor skill acquisition and integration of vestibular signals for postural control, and these changes have been positively correlated with performance in a complex balancing task²⁸. The same research group, utilizing functional and structural magnetic resonance imaging, reported increased neural connectivity one week after two motor training sessions²⁹. Gruber and Gollhoffer⁶ were also able to demonstrate significant increases in RFD and enhanced neural activation after only eight sensorimotor training sessions, supporting the contention that improved performance measures can be actualized with relatively few sessions of an UDP.

Clear increases in countermovement jump height and the 20-m repeated running sprint protocol attributable to the UDP were also noted, compared to the control group; however, the magnitude of these changes was relatively small. While improvements in countermovement jump performance have been reported previously following sensorimotor training⁸, we are not aware of any previous research on the effects of this training modality on repeated sprint performance. The improvement in repeated running sprint performance relative to the control group was likely resultant from the increased sprint speed and acceleration as no difference in fatigue measures (data not presented) were evident.

While the UDP generally compared favourably with the control group intervention, we did observe a relatively negative effect with respect to the landing forces experienced when clearing a 20-cm hurdle. While both groups decreased the landing impact forces as a result of the training interventions, the magnitude of the decrease (improvement) was greater in the control group. This observation may have been due to the fact that landing impact assessment protocol more closely resembled the training performed by the control group. Additionally, neuromuscular-based training without unexpected disturbances has also been shown effective in reducing impact forces during landing and improving hamstrings-to-quadriceps muscle peak torque ratio³⁰.

While every effort was made to control all aspects of the training intervention, we acknowledge that external aspects such as diet and sleep were not specifically controlled to limit any potential confounding effects. The random assignment of the athletes to parallel groups however does limit some confounding variables, as it is unlikely that external confounders would affect one group preferentially. We are also cognizant that the study conclusions are based on a relatively small sample size and that the interpretations should be considered with this in mind; nonetheless, due the elite nature of the participants and the high ecological validity inherent in the current study, we believe that the data set contributes to the pool of scientific knowledge. We would state that all available participants from this elite cohort were recruited and voluntarily participated. Lastly, note that the term 'substantial' was deliberately used herein to contrast the misunderstood term 'significant',¹³ which conveys no useful information regarding the meaningfulness or magnitude of an effect within a given population. The 'substantial' effects discussed here should therefore be interpreted as are both clear and meaningful, with their magnitudes quantified based on objective and population-specific thresholds.

CONCLUSIONS

The substantial improvements in running sprint speed and concentric-only jump performance lead us to concur with the statement by Gruber and colleagues⁶ that sensorimotor training is a “highly efficient” modality for improving explosive strength. The quantitatively large improvement in 5-m running sprint performance represents a highly desirable adaptation with respect to athletic performance. These results in elite female field hockey athletes may have important implications for injury prevention in this cohort and extend on our previous work whereby a UDP was demonstrated to be effective in enhancing performance outcomes in a rehabilitative setting. Thus, both rehabilitative specialists and strength and conditioning practitioners should be aware that incorporating exercises that specifically target the sensorimotor system through unexpected disturbances can be effective in improving physical performance measures.

REFERENCES

1. Zech A, Hübscher M, Vogt L, Banzer W, Hansel F, and Pfeifer K. Balance training for neuromuscular control and performance enhancement: A systematic review. *J Athl Train*. 2010; 45: 392-403.
2. Krosshaug T, Nakamae A, Boden B, Engebretsen L, Smith G, Slauterbeck J, Hewett T, and Bahr R. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med*. 2007; 35: 359-367.
3. Waldén M, Krosshaug T, Bjørneboe J, Andersen TE, Faul O, and Hägglund M. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. *Br J Sports Med*. 2015; 49: 1452-1460.
4. Teichmann J, Suwarganda EK, Lendewig C, Wilson BD, Yeo WK, Aziz RA, and Schmidtbleicher D. Unexpected disturbance program for rehabilitation of high performance athletes. *J Sport Rehabil*, 2015; 25: 126-132.
5. Fitzgerald GK, Axe MJ, and Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. *Phys Ther Sport*. 2000; 80: 128-140.
6. Gruber M and Gollhofer A. Impact of sensorimotor training on the rate of force development and neural activation. *Eur J Appl Physiol*. 2004; 92: 98-105.
7. Kean CO, Behm DG, and Young WB. Fixed foot balance training increases rectus femoris activation during landing and jump height in recreationally active women. *J Sports Sci Med*. 2006; 5: 138-148.
8. Taube W, Kullmann N, Leukel C, Kurz O, Amtage F, and Gollhofer A. Differential reflex adaptations following sensorimotor and strength training in young elite athletes. *Int J Sports Med*. 2007; 28: 999-1005.
9. Behm DG and Kibele A. Effects of differing intensities of static stretching on jump performance. *Eur J Appl Physiol*. 2007; 101: 587-594.
10. Baechle TR and Earle RW. *Essentials of Strength Training and Conditioning* Champaign, IL: Human Kinetics, 2008.
11. LeSuer DA, McCormick JH, Mayhew JL, Wasserstein RL, and Arnold MD. The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. *J Strength Cond Res*. 1997; 11: 211-213.
12. Turner AN and Stewart PF. Repeat sprint ability. *Strength Cond J*. 2013; 35: 37-41.
13. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009; 41: 3-12.
14. Batterham AM and Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform*. 2006; 1: 50-57.
15. Taube W. Neurophysiological adaptations in response to balance training. *Deutsche Zeitschrift für Sportmedizin*. 2012; 63: 273-277.

16. Beurskens R, Gollhofer A, Muehlbauer T, Cardinale M, and Granacher U. Effects of heavy-resistance strength and balance training on unilateral and bilateral leg strength performance in old adults. *PLoS One*. 2015; 10: e0118535.
17. Gusi N, Carmelo Adsuar J, Corzo H, Del Pozo-Cruz B, Olivares PR, and Parraca JA. Balance training reduces fear of falling and improves dynamic balance and isometric strength in institutionalised older people: a randomised trial. *J Physiother*. 2012; 58: 97-104.
18. Gruber M, Gruber SB, Taube W, Schubert M, Beck SC, and Gollhofer A. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *J Strength Cond Res*. 2007; 21: 274-282.
19. Schubert M, Beck S, Taube W, Amtage F, Faist M, and Gruber M. Balance training and ballistic strength training are associated with task-specific corticospinal adaptations. *Eur J Neurosci*. 2008; 27: 2007-2018.
20. Lauber B, Keller M, Gollhofer A, Müller E, and Taube W. Spinal reflex plasticity in response to alpine skiing in the elderly. *Scand J Med Sci Sports*. 2011; 21: 62-68.
21. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, and Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol*. 2002; 93: 1318-1326.
22. Myer GD, Ford KR, Palumbo JP, and Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res*. 2005; 19: 51-60.
23. Van Cutsem M, Duchateau J, and Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol*. 1998; 513: 295-305.
24. Aagaard P and Andersen JL. Effects of strength training on endurance capacity in top-level endurance athletes. *Scand J Med Sci Sports*. 2010; 20: 39-47.
25. West DJ, Owen NJ, Jones MR, Bracken RM, Cook CJ, Cunningham DJ, Shearer DA, Finn CV, Newton RU, Crewther BT, and Kilduff LP. Relationships between force-time characteristics of the isometric midthigh pull and dynamic performance in professional rugby league players. *J Strength Cond Res*. 2011; 25: 3070-3075.
26. Young W, McLean B, and Ardagna J. Relationships between strength qualities and sprinting performance. *J Sports Med Phys Fitness*. 1995; 35: 13-19.
27. Mero AA. Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Res Q Exerc Sport*. 1988; 59: 94-98.
28. Taubert M, Draganski B, Anwander A, Müller K, Horstmann A, Villringer A, and Ragert P. Dynamic properties of human brain structure: learning-related changes in cortical areas and associated fiber connections. *J Neurosci*. 2010; 30: 11670-11677.
29. Taubert M, Lohmann G, Margulies DS, Villringer A, and Ragert P. Long-term effects of motor training on resting-state networks and underlying brain structure. *Neuroimage*. 2011; 57: 1492-1498.
30. Hewett TE, Stroupe AL, Nance TA, and Noyes FR. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med*. 1996; 24: 765-773.

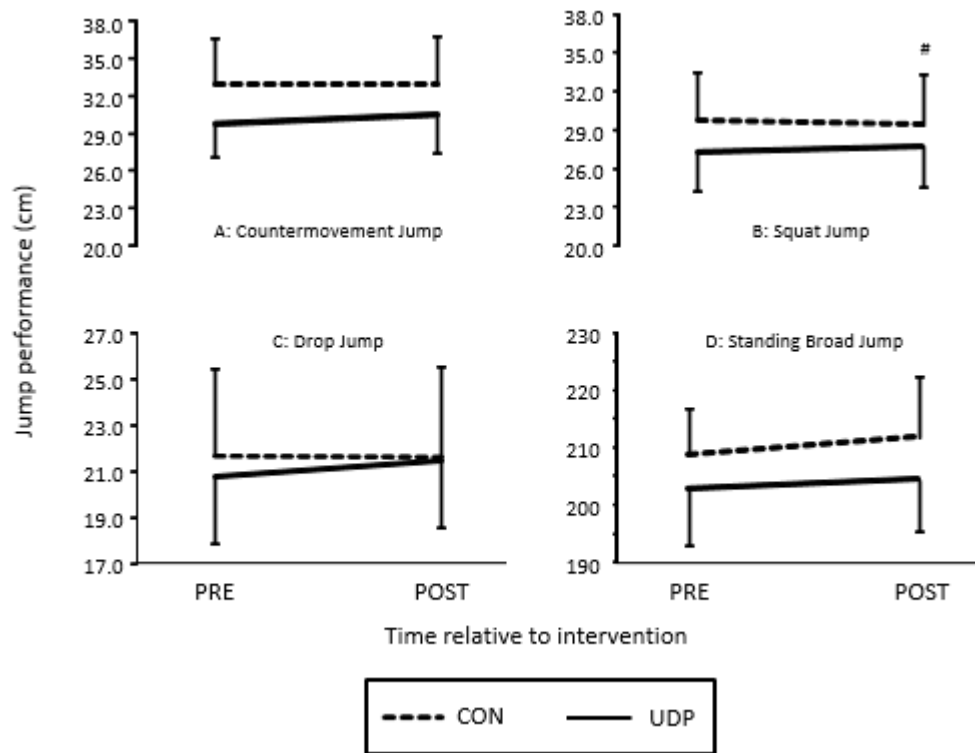


Figure 1: Change in the jump performance variables across the experimental period

CON: Control group; UDP: Unexpected disturbance group; #: substantially greater improvement in the UDP group.

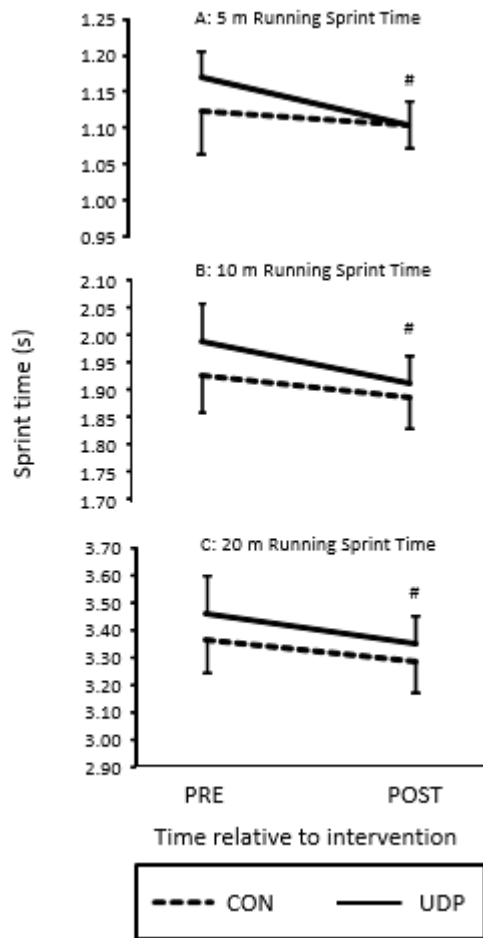


Figure 2: Change in the running sprint performance variables across the experimental period
CON: Control group; UDP: Unexpected disturbance group; #: substantially greater improvement in the UDP group.